The Fatique Strength of Reinforcing Bars in Concrete Beams

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In this article the factors affecting the fatique strength of reinforcing bar embedded in concrete are discussed. Research that have been made concerning the fatique strength of finnish reinforcing bars are described and a method for presenting the results in a practical mode is suggested.

Keywords: fatigue, reinforcement, steel, concrete

1. GENERAL

The fatique strength of reinforcing bars is usually based on the results of tests that have been carried out in air. This article deals with the most important factors affecting the fatique strength of reinforcing bars. There are many factors, which depend on the material the bars are embedded in. In order to abtain more realistic results the tests must be made with bars embedded in concrete and the beams in test must be as close the actual structure as possible.

Results which are described in the following are obtained from tests made by the author and from the litterature.

2. FACTORS AFFECTING THE FATIQUE PHENOMINA

The main parameters affecting the fatique strength in general are the stress range, minimum stress level and steel quality. The effect of these parameters is clear mithout further explanation.

Other parameters are:

Bar diameter

The bar diameter affects the reinforcing bars, but partly this effect is due to coldworking of the bars that is made by the rolling of the steel. This due to the fact that bars with smaller diameter have time to cool under hot-rolling thus getting actually some cold-working. If the diameter is larger than 12 mm this effect is strongly reduced.

Surface characteristics

Surface characteristics can be separated in four undergroups:

- geometrical properties of the lugs
- the degree of the wear of lugs
- the manufactorers mark
- mill scale and rust.

The geometrical properties of the lugs have been quite a lot studied in earlier years around the world. The parameters that belong in this category are the lug inclination, lug skewness other than perpendicular to the bar axis, the spacing, effective hight and the base radius of the lug.

Later research have however revealed that the bar surface in itself often have many crack initiate points as holes, "micro-alloy" local superficial defects, delamination, overrolling etc. the effect of these is often greater than the effect of bar characteristics. When these effects act simultaneously, a remarcable reduction in fatique strength is obvious.

Bending

Bending reduce the fatique strength up to 50 %. This type of reinforcing is usually used as stirrups and the it has been obtained that the negative effect of bending of the bar is applicable only to shallow beams h = 300...500 mm. If the beam is taller then the fatique failure occures in the middle portion of the beam, not in the area where the stirrup is bent. In other words the failure occures in the point where the shear stress is highest.

The beam type

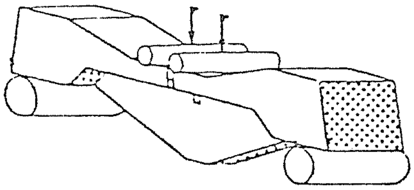
Soretz /1/ made tests with six different types of beams having the same type of reinforcment. The beam types are shown in figure (1). Some of the beam types showed lower fatique strength for the bars as others. Even the scatter of the results was larger in some beam types. No significant difference could be found between bent beam types and others. This means that the beam type includes not only geometrical differences but also the placement of reinforcing, strirrups etc.

The difference between different beam types is clarified by figure (2), in which in diagramform is shown the ultimate strength as function of the minimum stress level. The figure shows also that beams can roughly be brouped in two groups with internally alike fatique stress results. The dark area in the figure shows the area where the minimum stress level lies in structures of common practice.

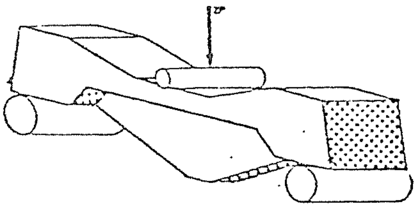
Embedding in concrete

The problem of the fatique strength of reinforcing bars embedded in concrete compared with similiar bars tested in air is much type of test beam

A



B and I



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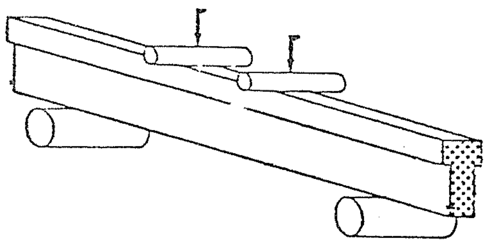

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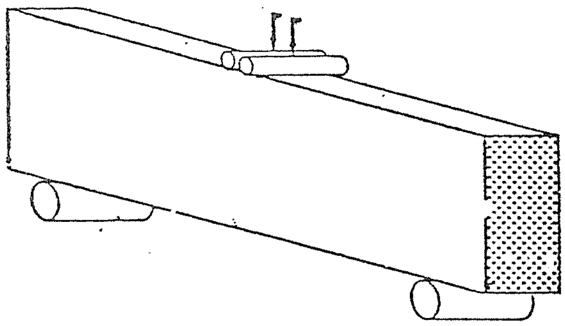
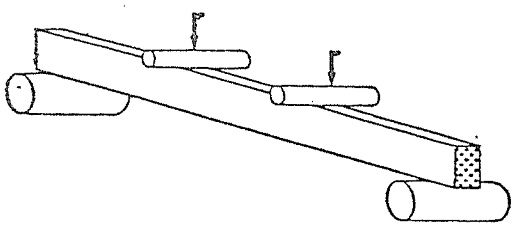


E and II



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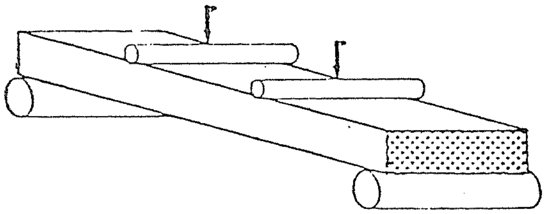
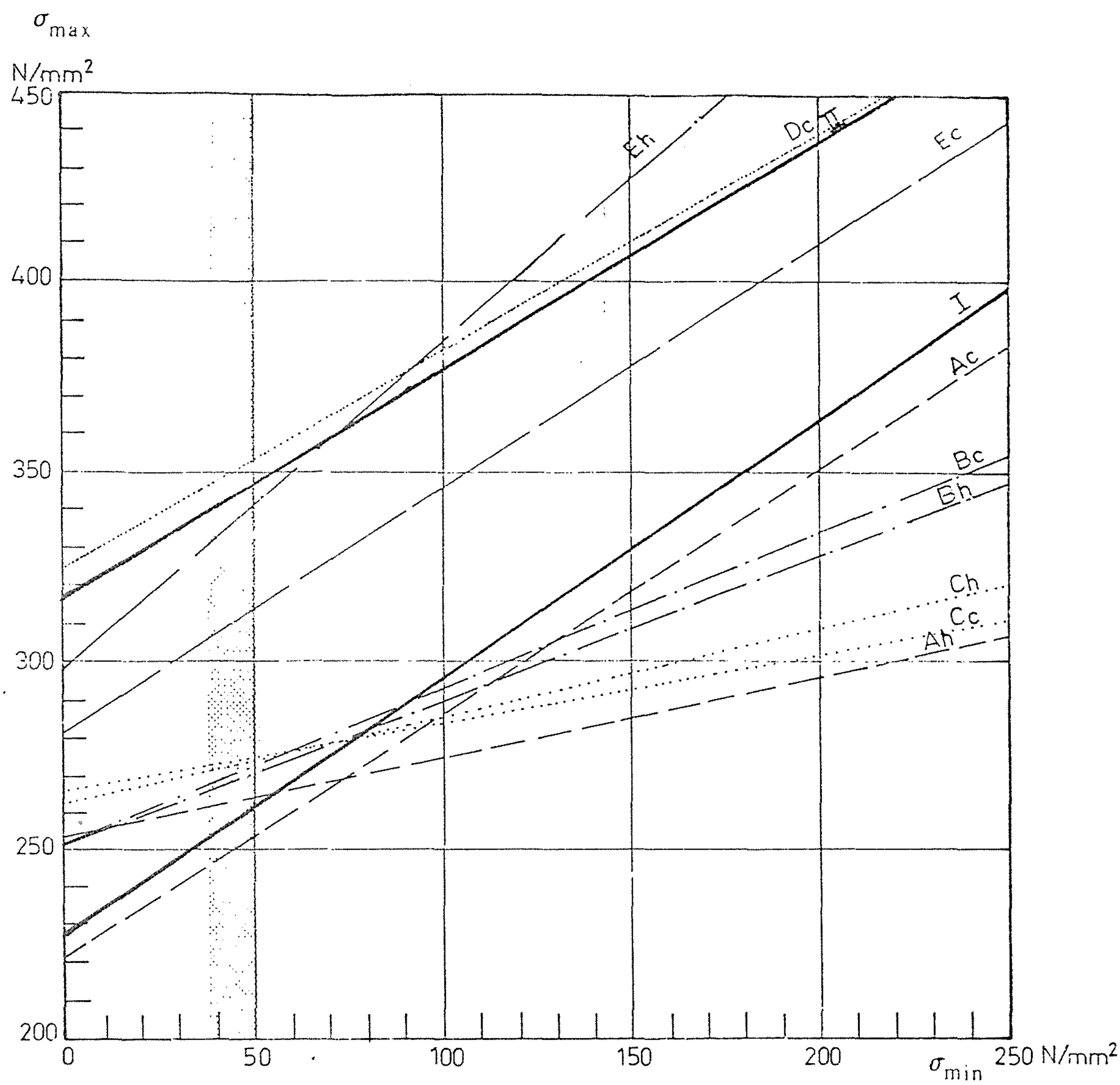


FIG 1 The symbols for different types of test beams



Symbols A, B, C, D, E, I and II are described in figure 1. Index h means hot-rolled and c coul-twisted bars.

FIG 2 The ultimate stress in different kinds of beams in fatique tests as a function of minimum stress level

discussed. No final answer have been found due to the great number of parameters affecting the result. Some of the reasons why results are different in different tests are given in /2/.

Stress concentration which takes place at the lug base are at the ultimate load according to figure 3. In practice the lug profile is seldom like the ideal one, it can have local defects even

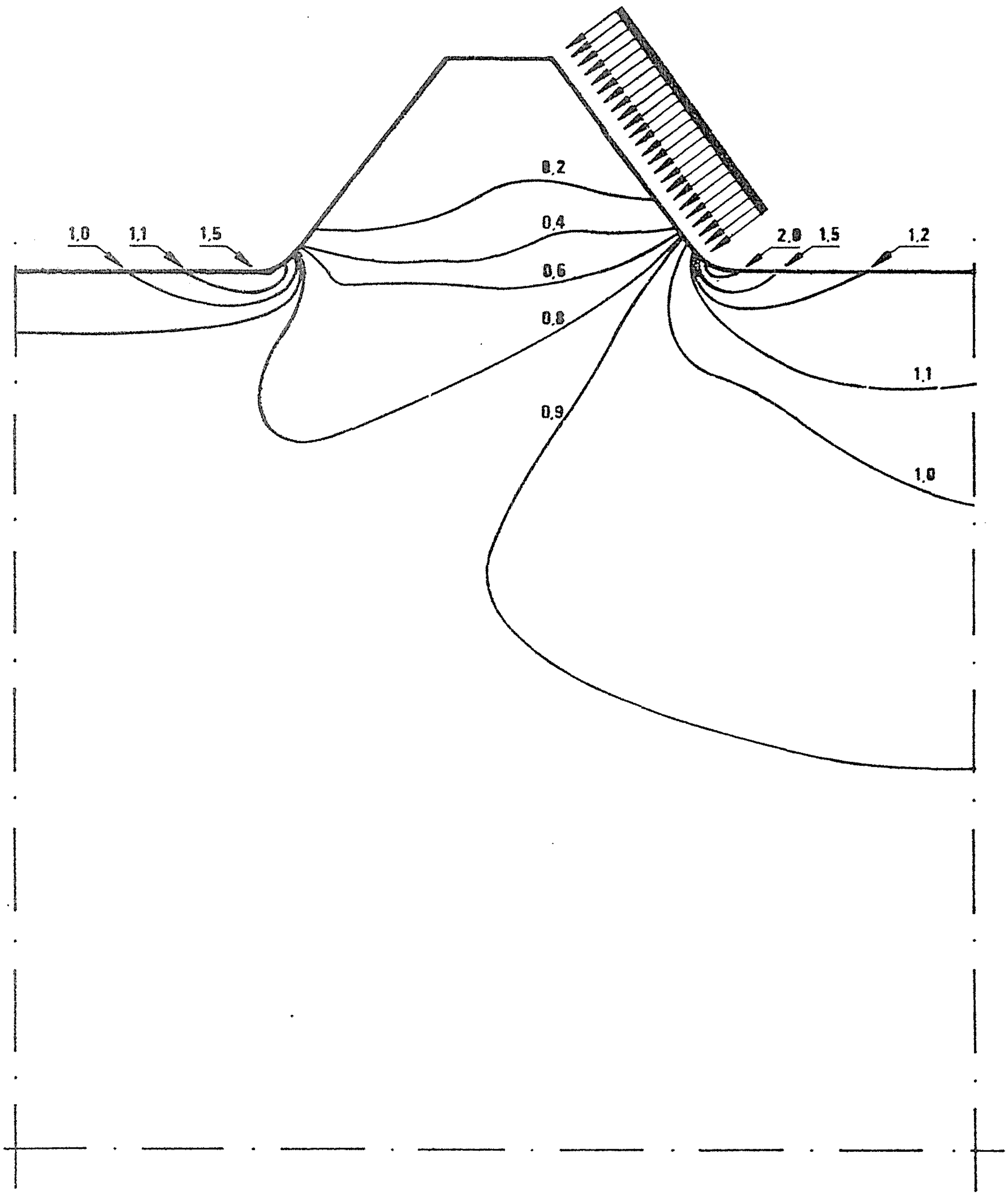


FIG 3 Contour map of ultimate stresses for an 8 mm bar embedded in concrete K 30. The average stress in steel bar is equal to unity.

going towards the center of the bar etc as it has been mentioned already when describing the effect of the geometrical properties of the lug.

Other types of parameters affecting the fatigue stregth of reinforcing bars such as welding and loading frequence are not treated here due to their different nature.

3. DETERMINATION OF THE FATIQUE STRENGTH OF A REINFORCING BAR

The determination of the fatique strength of reinfocning steel is normally made by tests with bars in the air. This due to the fact that it is a lot cheaper and less time consuming test arrangement. Time is also saved through the fact that the loading intensity can be increased when testing in air compared with tests with bars embedded in concrete.

If one wants to obtain results that are as like the real structure as possible it is most safe to make the tests with reinforcing bars that have been grouted in beams or similiar structures which resemble as much as possible the form of the real structure. This is however seldom possible due to the great variety of forms in practice as tests can not be made for each individual case.

As a compromise of the above mentioned two alternatives there have been used several types of "standardised" test beams. One of the types according to DIN-standard has a bent bar which resembles bending in the real structure. More common types of test beams include however straight bars.

Soretz have made fatique tests with beams of several different types /1/. According to his results is the effect of beam type is up to 30 %. The author has made tests with finnish reinforcing steel with beams of two of the types that Soretz used and the results are remarcable alike (types I and II in figure 2).

4. ANALYTICAL MODEL

Outgoing from the laws of the fracture mechanisms different models have been developed for describing the fatigue phenomina.

The most commonly used law is so called Paris´ law

$$\frac{da}{dN} = C\ (\Delta K)^m$$

where
- a is the crack length
- N is the number of stress cycles
- C is a factor that depends on the average stress level used
- K is the stress concentration factor
- m is a material factor

Knowing the material factor and the factor for the average stress level the fatigue life for different kind of objects can be calculated by means of the stress concentration factor. Embedding in concrete however, brings new parameters due to the fact that concrete is in macro scale a very unhomogenous material.

5. FATIGUE STRENGTH OF FINNISH REINFORCING BARS

The fatigue stregth of finnish reinforcing steel have been studied through tests with bars in the air as well as with bars embedded in concrete. With tests in the air /3/ there have also been developed different methods for treating the bars especially with shot peening in order to increase the fatigue strength considerably.

Bars embedded in concrete have been used both in traight beams as well as in bent beams according to the type described in DIN-standard /4/.

Through statistical treatment of test results there have been found that the fatigue stregth of finnish reinforcing steel is f_{fat} = 250...290 N/mm^2 depending on loading frequency, embedding in concrete etc. When taking into starting point the results of tests made with bars embedded in concrete there is a more realistic base for coding the fatigue phenomina in concrete codes.

With shot peening treated bars have been tested only in air. The results for this type of treated bars are f_{fat} = 400 N/mm^2 that means only slightly below the yield point.

6. TAKING INTO ACCOUNT THE FATIGUE STRENGTH OF REINFORCING STEEL IN CONCRETE CODES

In coding it is essential to present matters in as simple form as possible in order to avoid errors due to misunderstandings. This means that the way of presentation must be such that the basic parameters are presented clearly without mixing them in complicated formulas. This is true especially in case of fatigue, as an average projecting engineer is not daily dealing with the phenomina of fatigue.

In case of fatigue the main parameters are the characteristic fatigue strength and its dependance of the number of loading cycles and the average stress level. If patial safety factors for material are used, they can be included in the values or excluded depending on the way they are presented in other codes for building materials.

In Nordic guidelines for concrete codes /6/ an idea of presenting the fatigue strength in form of a simplified Wöhler diagram is given. An example of such diagram is given in figure 4.

In order to draw this kind of diagram there must have been established a certain point for the average stress level or for the minimum stress levels up to wich the diagram is applicable. If using higher minimum stress levels, one has to make use of a siplified modified Goodman diagram, too (figure 5).

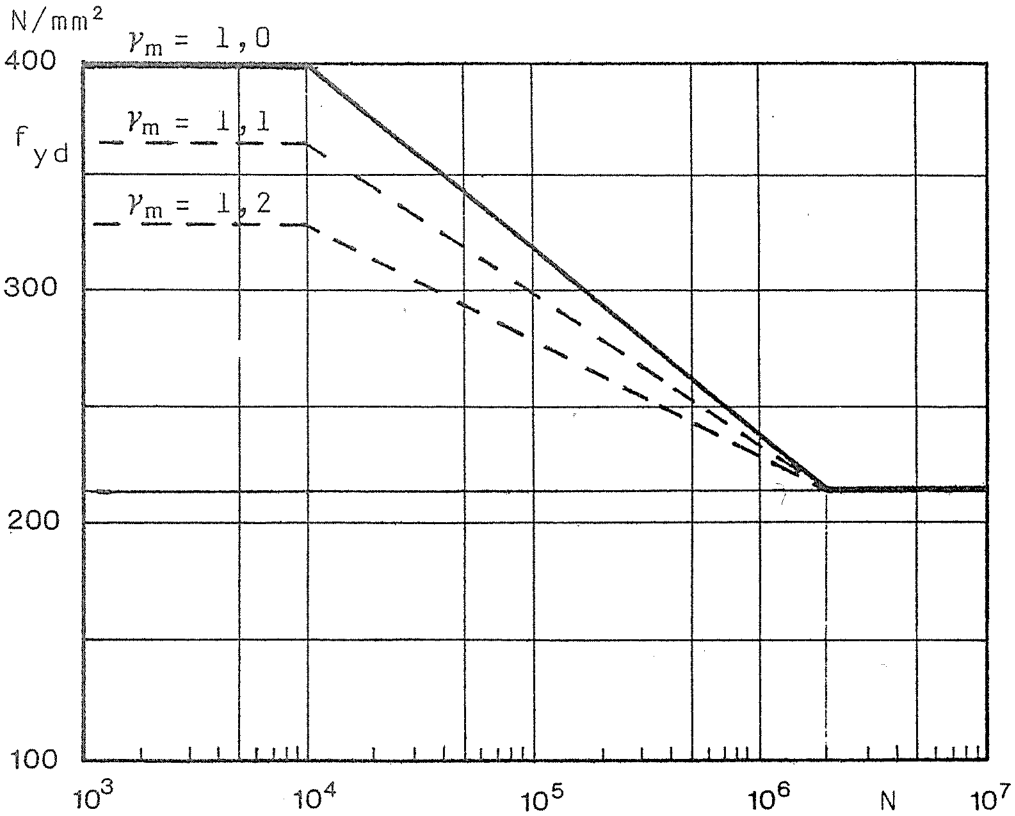


FIG 4 Simplified Wöhler diagram for the design fatigue stregth of finnish reinforcing steel

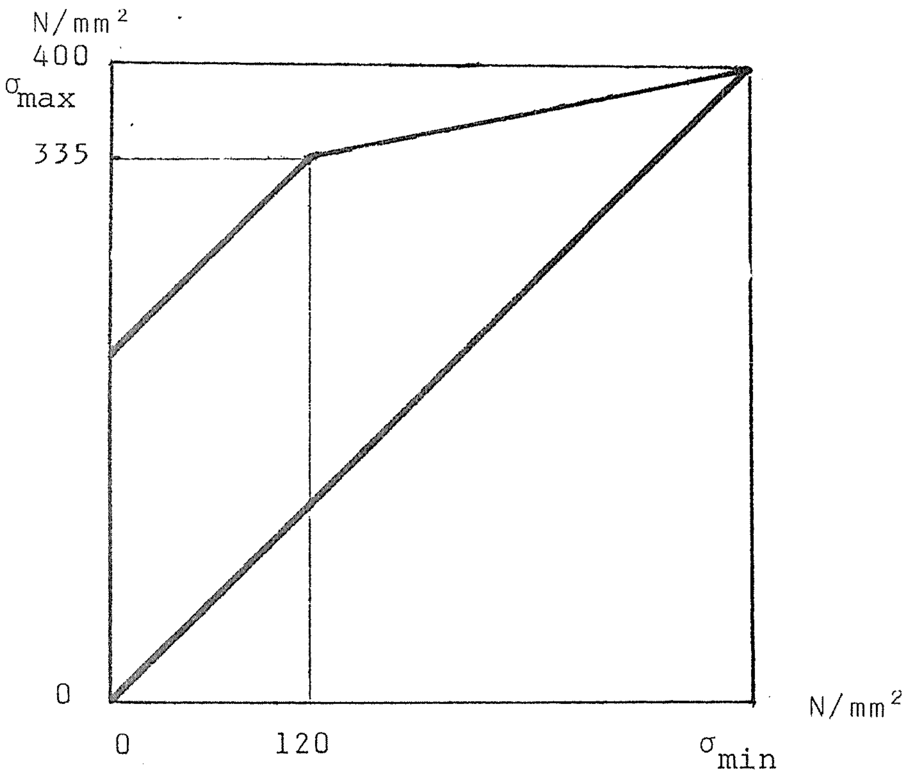


FIG 5 Simplified modified Goodman diagram for the design fatigue stregth in figure 4

REFERENCES

/1/ Soretz S.: Contribution to the fatigue stregth of reinforced concrete.
Abeles symposium Fatigue of concrete, ACI-publication SP-41, Detroit 1974

/2/ Weck T-U.: Armerade betongkonstruktioners säkerhet mot utmattningsbrott i armeringen. Helsinki 1981 (in swedish)

/3/ Kari A.: Investigations on the improvement of corrosion resistance and stregth of ribbed reinforcing steel bars in concrete specially when subject to fatigue loading. VTT, Building technology and community development, Publication 17, Espoo 1980

/4/ DIN 1045, Beton- und Stahlbeton; Bemessung und Ausführung Deutscher Ausschuss für Stahlbeton im Deutschen Normenausschuss, Berlin 1972